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Seamless Navigation using UWB-based Multisensor System

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Abstract— **This work presents an Ultra-wideband-based (UWB) approach to seamless positioning and navigation applied in a real test-bed. It deploys two different solutions for positioning estimation in function of the operational environment. Outdoors, a classical hybridization between Global Navigation Satellite System (GNSS) and Inertial Measurement Unit (IMU) is applied while indoors, an UWB/INS integration is performed relying on a low-cost commercial platform which integrates both UWB unit and IMU. The implementation of this procedure will be presented with more details in the paper. The aim of the work is to validate the performances in term of accuracy, precision and seamlessness behavior of the low-cost UWB technology available today. The results shown an overall accuracy of about 60 cm considering the entire path walked, both outdoor and indoors.**

Keywords—Ultra wide band; data fusion; multisensor; GNSS; INS

I. INTRODUCTION

Seamless positioning is the capability to estimate continuously the location of a body in the transition between outdoors spaces and indoors environments assuring accuracy, availability, continuity, reliability and integrity at different levels in function of the application requirements. Therefore, the transition is not only between different environments but also between navigation modes and services [1]. In case of outdoor navigation, the Global Navigation Satellite Systems (GNSS) performances have been deeply demonstrated and evaluated unlike the indoor positioning systems which are composed by a wide panorama of new technologies and methods with different characteristics which yields different performances. Cameras [2] [3], infrared (Kinect), ultrasound [4], WLAN/WiFi [5], [6], mobile communication [7] and so forth are examples of the technologies that the scientific community has put at the service of indoor location. All these positioning systems have pros and cons that make them more useful in specific scenarios, compared to other options.

Many research studies performed on this wide plethora of technologies, have hybridized the GNSS with other positioning techniques for reaching the seamlessness of the navigation. One of them is represented by Ultra-Wideband systems (UWB), a very popular indoor positioning and navigation systems based on impulse of radio frequency carrier-less signals, whose characteristics gives major advantages with respect to other indoor localization techniques such as Wi-fi or pseudolites [8]. All the technologies using radio frequencies as a physical quantity to define the location have some common issues linked with the necessity of the line of sight (LOS), signal noise corruption, and problems of propagation and multipath [9]. UWB systems are slightly better on manage these problems with respect to similar radio frequency-based techniques. Firstly, the very short pulses used in transmission, results in a wide spectrum band due to the inverse relationship between time and frequency. This means the capability of the system to measure and discretize transmission and reception times with high accuracy. High time resolution means also precise range measurements and consequently good exploitation in the positioning estimation. The characteristics of the signal and the transmission implementation allow to develop a relatively simple architecture for these sensors which can be produced as low-cost technology. Therefore, a network configuration is easily implementable and scalable in function of the coverage needs for indoor positioning [10]. This network of sensor can be seen as a constellation of fixed satellites with known position, therefore the UWB can easily replace the GNSS in a sensor fusion hybridization like the well-established GNSS-Inertial Navigation System (GNSS/INS) integration.

A new push on research related to UWB positioning is given by the possibility of installing such low-cost sensors within mass-market devices. In this regard, Apple was the first to insert a UWB sensor into the latest generation of smartphones. This novelty, together with the presence of dual frequency receivers [11] and 5G capabilities [12], means that the mobile phone becomes a multi-sensor platform capable of integrating the majority of indoors and outdoors positioning techniques.

The remainder of this paper is organized as follows. In Sec. II the Material and Methods used to perform the seamless navigation are provided. Hardware and software used to acquire real time data are well described together with the theoretical approach of the present work. Sec. III describes the experimental setup, the georeferencing procedure of the test area and the acquisition of the reference solution. In Sec. IV the results of the positioning estimation and his validation is discussed.

II. MATERIALS AND METHODS

The proposed methods to perform seamless pedestrian navigation is composed of two different strategies that differ according to the environment in which the system is operating (outdoor or indoor) and therefore according to the measurements available at a given integration time. As well known, in outdoor spaces, the GNSS is the fundamental technology to perform pedestrian navigation. The four main satellite constellations (GPS, Galileo, GLONASS and Beidou) guarantees enough satellite visibility worldwide, ensuring any receiver on the Earth surface to acquire the GNSS signal and therefore to estimate their own position with classical positioning methods and approaches. The quality of the observations i.e. pseudoranges between the receiver and the satellite, together with several estimation techniques, bias modeling and data fusion algorithms, allows nowadays to reach an accuracy of less than 1 meter also with very low cost receivers and antennas. In this research, a very low cost GNSS receiver has been used to acquire both raw data and position estimation therefore, as the goal of the research is to perform accurate positioning and navigation, the observation bias must be subtracted using correction provided by a network of fixed geodetic receiver located on the local territory. This approach must be applied real time with very low cost receiver like the ones embedded in smartphone device as demonstrated in authors previous works [13], [14]. Furthermore, in order to further improve positioning, the inertial data acquired during pedestrian motion can be integrated with the GNSS data in a loose coupling, typical in kinematic positioning [15]. In indoor scenario, the UWB-base positioning is the main technology used in this work. Similarly to the GNSS, also UWB provide ranges between a receiver and several anchors deployed in the environment. Again, the multilateration allows to estimate the position, which can be increase in term of accuracy using the inertial data acquired by an Inertial Measurement Unit. Before to describe the methodology a general overview on hardware sensors and programming tools used in the present research will be given.

A. Hardware

The UWB-based multisensory system used in this research consist in a set of hardware integrated in order to acquire and process in real time the different data provided by each technology. The computational load of the positioning estimation algorithm is delegated to a Raspberry Pi board which manage also the serial communication and the time synchronization. The main characteristic of this system is the very low cost of the sensor which nowadays can be easily found in new generation smartphones. The GNSS module is the NEO-M8N Ublox, a dual frequency, multiconstellation receiver developed for automotive application. The UWB system is the Pozyx accurate positioning system ®, a Real Time Locating System (RTLS) based on Two Way Ranging techniques. The inertial acquisitions are demanded to an IMU composed by a three-axis accelerometer, three axis gyroscope and three axis magnetometer and also a microbarometer. TABLE I. summarize the principal characteristics of these sensors together with their performances and cost.

TABLE I. PERFORMACE SPECIFICATION OF MULTISENSOR SYSTEM

GNSS	UWB	IMU	CPU
NEO-M8N Ublox	**Pozyx**	**Pozyx**	**Raspberry Pi 3 Model b+**
Constellation: GPS/GLONASS /Galileo/BeiDou	3D position accuracy: 30 cm	3 axes Accelerometer, Gyroscope and Magnetometer	OS: GNU/Linux
2D position accuracy: 2,5 m	Antenna: Decawave DW1000	Roll 2 deg Pitch 5 deg Heading 4 deg	Ports: 4 USB 2.0; 1 Ethernet
Max navigation update rate: 5 Hz	Max Positioning update rate: 140 Hz	Max Update Rate: 100 Hz	RAM: 512 MB
-	Max Ranging update rate: 80 Hz	-	-
-	Typical LOS range: 30 m	-	-
Cost: 22,00 €	Cost: 500,00 €	Embedded in Pozyx	Cost: 25,00 USD

To assess the accuracy of the estimation algorithm a reference solution is required. When a kinematic test is conducted, the irregular path of the pedestrian must be tracked with an accuracy much higher than the accuracy of the device to be validated. In this work, the ground truth was acquired with a topographic total station with the ability to autonomously lock to and track a prism target. In particular, two total station has been used in order to cover both the indoor and the outdoor part of the acquisition (the Leica MS50 and the Trimble S7 tracking a Leica GRZ122 360 degrees prism). Finally, a Raspberry Pi 3 Model B+ with Ubuntu OS installed was used to manage the data acquisition, the communication protocols and the timing of the different sensors. The total cost of the UWB-based multisensory system is about 600,00 € comprehensive of the anchors network installation.

B. Methods

The proposed methodology for seamless pedestrian navigation is composed by two main steps: the firs, when there is satellite visibility, is based on GNSS, Inertial platform and UWB sensor hybridization while the second, relies only on the data fusion between IMU and UWB. These two cores are integrated to obtain an unique continuous navigation solution providing positioning, velocity and attitude information of the platform previous presented. The currently proposed solution could be easily obtained with better performances from available commercial device and previous researches which exploit high grade sensors with an high cost. When low-cost sensors are used, the feasibility of the navigation becomes more challenging and the quality of the estimated solution decrease.

The procedure of the proposed algorithm is presented in Fig. 1. The estimation state is composed by position (latitude, longitude, altitude), velocity vectors along the north, east and down axis, attitude (roll, pitch, heading), acceleration and gyroscopic bias. An EKF is used to perform prediction and update state estimation, the filter is used in feedback form so that when a measurement is available from a sensor, the error is computed using the Kalman filter which is then used to correct the inertial sensor measurements and navigation parameters. On top of this algorithm is also possible to introduce relative altitude estimation from a barometer sensor and heading compensation from magnetic measurements.

The GNSS receiver and the Pozyx GNSS inertial sensor unit are the systems that integrated in a loosely coupled algorithm represent the starting navigation solution for the outdoor space. The GNSS receiver provide position at 1 Hz, while the IMU works at 4 Hz. This high rate is fundamental to fill the gap between two subsequent GNSS measurements. The GNSS position and velocity are used to estimate the INS error. When the systems move indoor the GNSS receiver is no more able to provide measurements so it has been substituted by the UWB receiver that enters in the UWB network of fixed anchor nodes. Also the UWB can work at 1Hz providing positioning in the indoor environment. The previous loosely coupled integration is used in this case simply using the UWB data to update the INS navigation. Fig. 1 present the methodology of our approach.

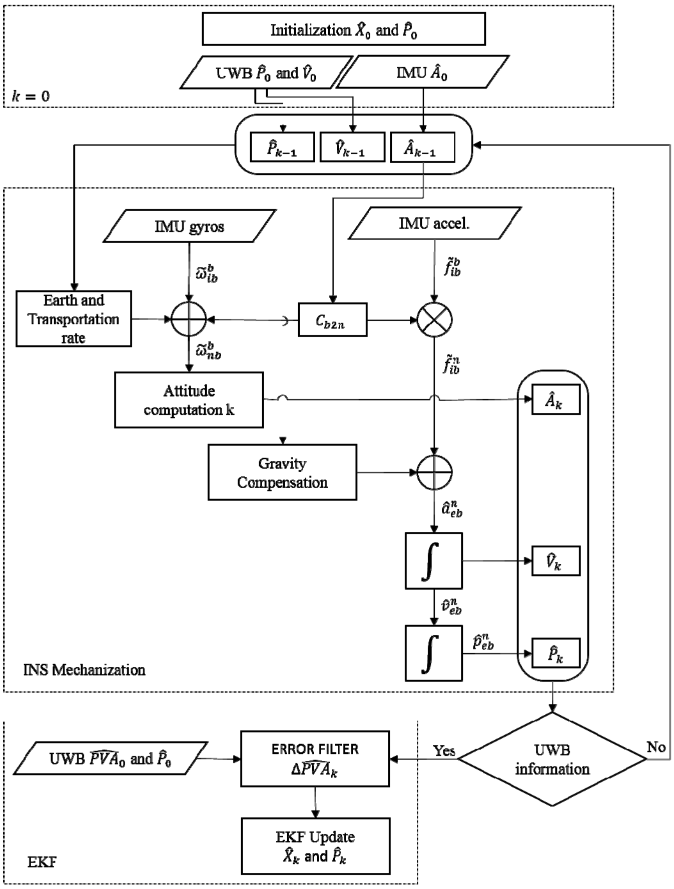

Fig. 1. Methodology for UWB/ INS data fusion.

III. EXPERIMENT

The data acquisition of the different sensors used in this work was performed on September 2019 in the Photogrammetry, Geomatics and GIS Laboratory of the Environment, Land and Infrastructure Engineering Department of Politecnico di Torino, Italy. The laboratory, represented in Fig. 2., is composed by an indoor space with several working station and an outdoor space, a terrace, which characteristics are similar to an urban canyon with very low satellite visibility. The first step of the experiment was to install the network of UWB anchor in the environment. Again, in Fig. 2 is possible to observe the location of these device. Although these systems are capable of performing a self calibration, to obtain a high accuracy in estimating the position, it is necessary to measure each node of the network with topographical methods. For this purpose, an integrated topographic survey was carried out. It is important to underline that all the measures of the topographic network have been traced back to the geographical coordinates in a UTM-WGS84 system, thanks to the use of geodetic GNSS receivers (Leica GS14 and GS18). In this way, the integration between GNSS and UWB measurements took place within the same reference system.

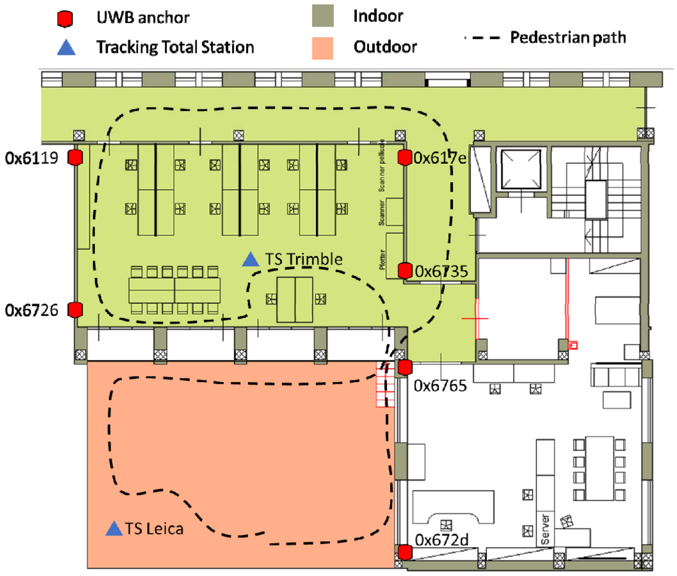

Fig. 2. The pedestrian path, the UWB anchor location and the indoor/outdoor spaces.

TABLE II. COORDINATES OF THE UWB NETWORK IN UTM-WGS84 32N

Point	East [m]	North [m]	H ellips. [m]
TS Leica	394547.830	4990864.307	302.566
TS Trimble	394540.988	4990878.101	303.492
0x6726	394541.794	4990871.963	305.888
0x6119	394535.877	4990875.138	305.985
0x617e	394541.642	4990886.423	306.157
0x6735	394546.468	4990883.866	305.827

0x6765	394550.462	4990881.682	305.869
0x672d	394556.253	4990879.496	305.554

The data acquisition was performed assembling all the sensor in an handled platform together with a LCD screen for real time error checking and a prism mounted on the top. Each lever arm between the sensors (GNSS antenna, UWB antenna, 360° prism) was measured with a caliber and are shown in Fig. 3. The positioning algorithm was performed in real time through the Raspberry Pi processor. The data acquisition, the communication protocols and the processing were made all in the same python environment.

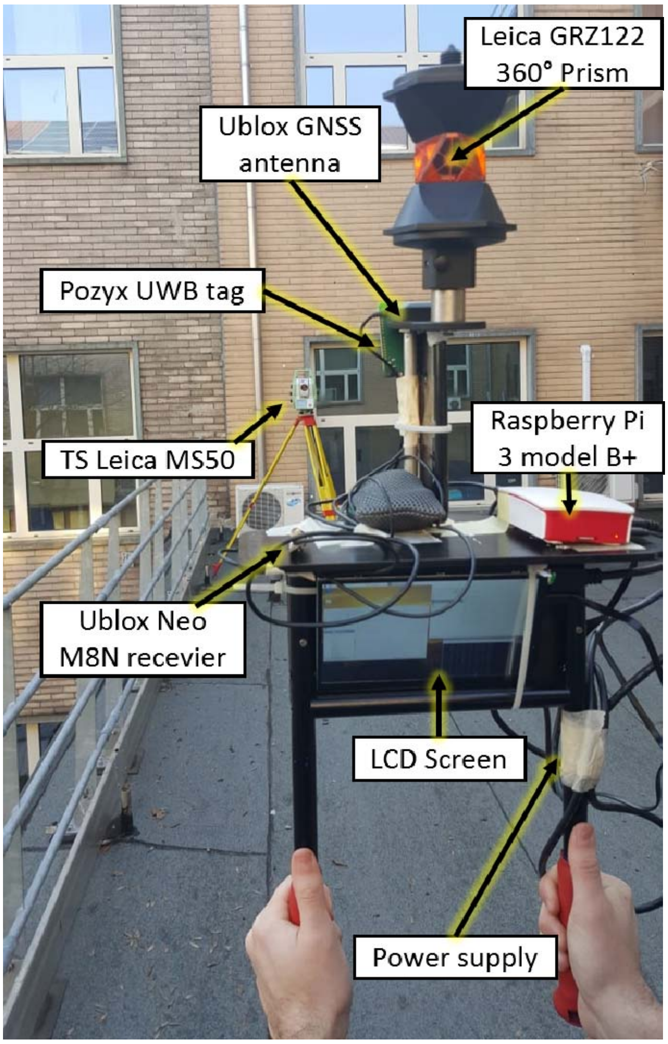

Fig. 3. Multisensor platform tracked by the Total Station during the data acquisition campaign.

A major issue was the to provide to the EKF the GNSS state vector already processed in NRTK mode. To do this, the Ublox receiver was connected via USB port to the Raspberry board which, through the **str2str** module of the RTKLIB suite ver. 2.4.3, takes the GNSS signal coming from the antenna and redirects the flow on a raspberry TCP/IP port. This flow is then split into two, one is saved as a raw observations file for quality check while the other it has been used as **rtkrcv** module input for estimating an Network Real Time Kinematic (NRTK) positioning using the network of permanent SPIN stations (Servizio di Posizionamento Interregionale GNSS) and the virtual reference correction station (VRS). This choice was made as it represents the real time positioning solution which allows the achievement of centimetric precision and accuracy. Finally, this solution is used as input for the integrated positioning algorithm presented in this work. The same flow acquired by the IP/TCP port is also saved for a quality analysis and for the possibility of post-processing the data with other techniques. The presence of raw GNSS observations of code and phase allows the implementation of tightly coupled approaches subject of future work (Fig. 4).

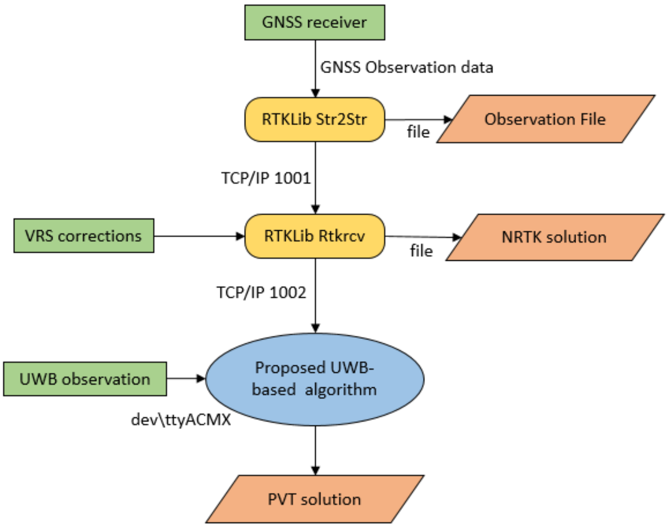

Fig. 4. Communication protocols and signal flow management.

IV. RESUTS AND VALIDATION

To verify the accuracy of the proposed algorithm in performing seamless navigation estimation of pedestrian, firstly we have conducted several experiments consisting in an user walking along a random path from the outdoor terrace to the indoor laboratory. The user walked for a short period outside the laboratory and therefore outside the UWB network. This allows also to analyze the behavior of the algorithm in no-line-of-sight (NLOS) conditions and with less anchor to observe. The results are shown in Fig. 5 for one representative test.

To evaluate the accuracy of 3D position estimation, an analysis on the difference between the estimated position and the reference one was made (Fig. 6, Fig. 7, Fig. 8). TABLE III. report the statistical results along the three components (East, North, Up) and the total 3D RMSE.

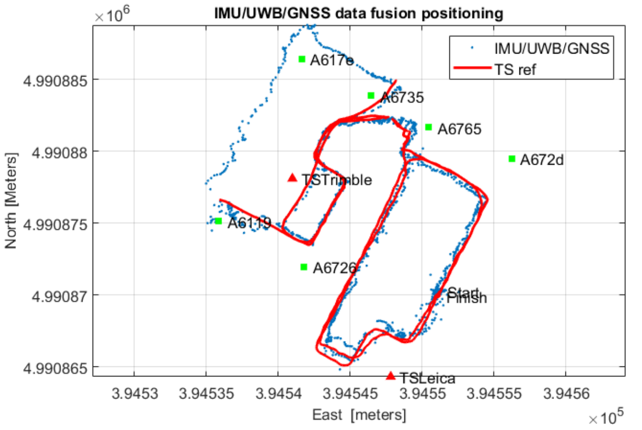

Fig. 5. The horizontal 2D positioning estimation in UTM WGS84 cartographic system.

TABLE III. STATISTICAL PARAMETERS-

Statistics	East	North	Up	3D
Min RMSE [m]	0,025	0,034	0,094	0,046
Max RMSE [m]	1,064	1,781	2,782	1,983
Mean RMSE [m]	0,019	0,081	0,182	0,653
Std.D RMSE [m]	0,275	0,349	0,653	0,488

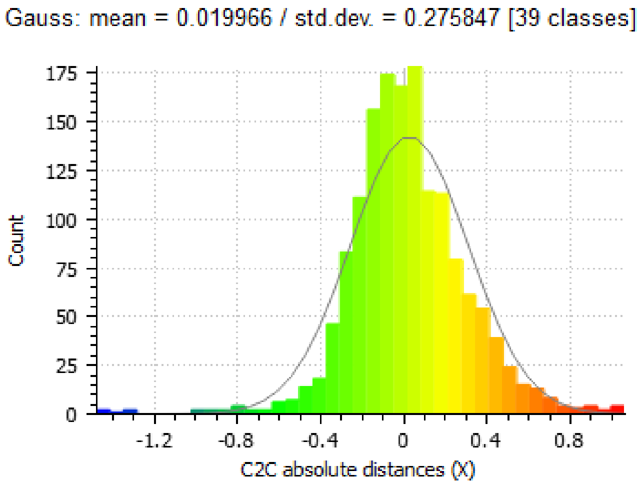

Fig. 6. Histogram and distribution of the positioning discrepancies along East direction.

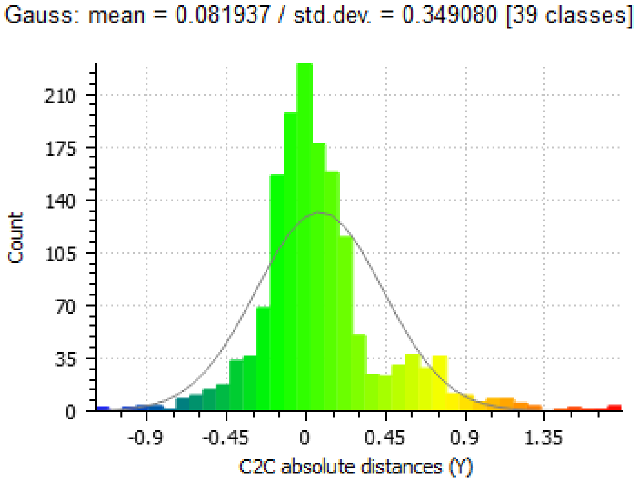

Fig. 7. Histogram and distribution of the positioning discrepancies along North direction.

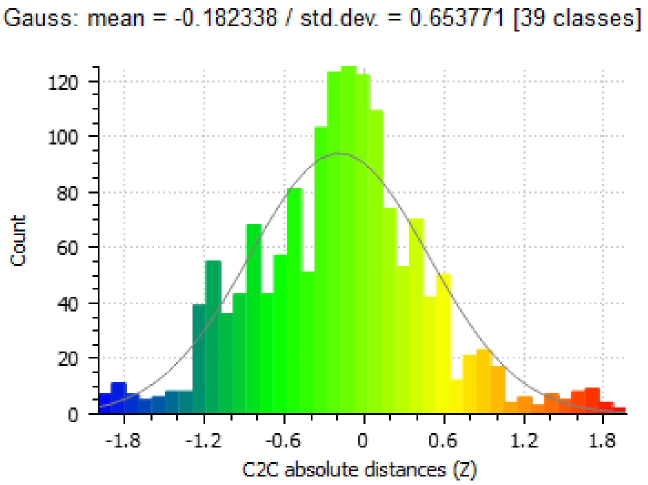

Fig. 8. Histogram and distribution of the positioning discrepancies along Down direction.

Another parameter considered for the validation of the algorithm was the Walking Difference Distance (WDD) between the total travelled distance considering the reference data (total station tracking) and the estimated one. TABLE IV. reports the results for five different paths.

TABLE IV. WALKING DISTANCE ESTIMATION.

Lap	Reference WD [m]	Estimated WD [m]	WDD [m]
1st	163	201	38
2nd	186	193	7
3rd	165	188	23
4th	220	193	27
5th	172	188	16

V. CONCLUSIONS

Previous research on the performances of the Pozyx UWB positioning system have shown an accuracy of the positioning estimation in kinematic condition of about 30. The performances of this system are strongly affected by the environmental conditions in which the system operates. The main issue is represented by the No-Line of Sight conditions (NLOS) where furniture, people, walls and obstacles decrease the time measurement capability of the system. Moreover, the presence of reflective surfaces, like glass windows, affects also the accuracy of the system. Outdoor, the GNSS technology allows to reach centimetric level of accuracy in open sky condition and with differential corrections. Combining these two technologies, is possible to obtain a seamless navigation solution, i.e. a continuous and reliable positioning solution in the transition between an outdoor environment to an indoor space. The present work presents an UWB-based multisensory systems composed by low-cost sensors and a methodology for real time data acquisition and processing. The results shown an overall accuracy of about 60 cm, with a major positioning error in the area of transition between outdoor and indoor spaces and in NLOS condition. The work has demonstrated the possibility to use UWB system as integrated sensor in a seamless navigation solution.

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